Embedded Perception & Decision-making for Safe Navigation in Uncertain, Dynamic and Human-populated Environments

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Invited Talk – *Coboteam Workshop on "Robots Navigation"*
France, On-line event, May 28th 2020

Focus on Autonomous Vehicles

inria informatics mathematics

NANOELEC.

Technology status & Ongoing challenges for AVs

- **Strong involvement of Car Industry & GAFA + Large media coverage + Increasing Governments supports**
- **An expected market of 515 B€ at horizon 2035** *(~17% world automobile market, Consulting agency AT Kearney, Dec 2017)*
- **But Validation & Certification issues are still unclear … idem for Legal & Regulation issues**

=> Numerous experiments in real traffic conditions since 2010 (Disengagement reports => Insights on system maturity)

=> But still insufficient … Realistic Simulation & Formal methods are also under development (e.g. EU Enable-S3)

Millions of miles driven since 2010 (Google, Tesla, Waymo, Uber, …)

Several benign & serious accidents in past few years

Safety is still not guaranteed !

Tesla Autopilot L2 with Radar & Mobileye/Intel
Commercial ADAS product => ***Tested by customers …***

Numerous EU projects in last 2 decades
Cybus, 3 months experiment, low speed La Rochelle 2012 (France)

Dense 3D mapping & Numerous vehicles
10 years R&D, 8 millions km covered since 2010 & 25 000 km/day

Drive Me trials (Volvo, 2017)
- *100 Test Vehicles in Göteborg, 80 km, 70km/h*
- *No pedestrians & Separations between lanes*

"Self-Driving Taxi Service L3" testing in US *(Uber, Waymo)* & Singapore *(nuTonomy)*

⇒ ***Autonomous Mobility Service****, Numerous Sensors + "Safety driver" during testing (take over in case*

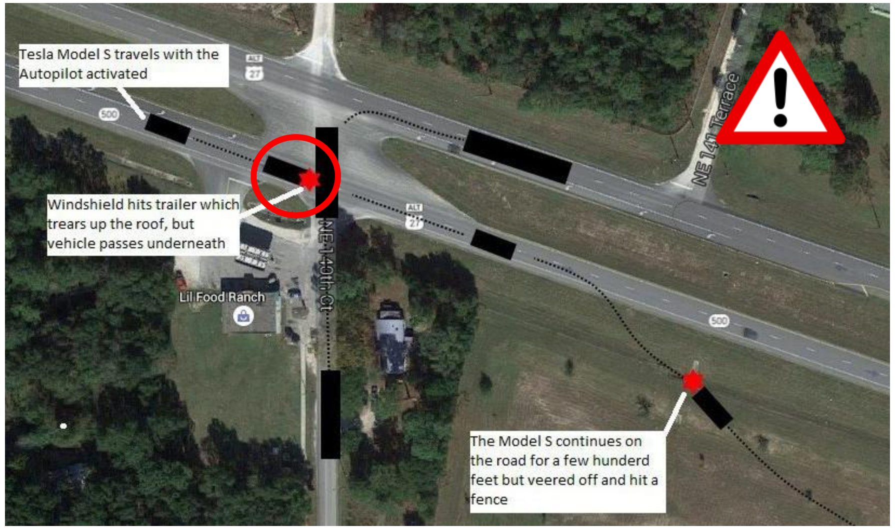
⇒ ***Uber:*** *System testing since 2017, Disengagement every 0.7 miles in 2017 (improved now)*

⇒ ***Waymo:*** *1st US Self Driving Taxi Service launched in Phoenix in Dec 2018*

⇒ ***Disengagement reports provide insights on the technology maturity***

Fatal accidents involving AVs – *Perception failure*

❑ Tesla driver killed in a crash with Autopilot "level 2" active *(ADAS mode) – May 2016*



- ✓ ***The Autopilot <u>failed to detect</u> a white moving truck, with a brightly lit sky*** *(Camera Mobileye + Radar)*
- ✓ ***The human driver was not vigilant & didn't took over***

❑ Self-driving Uber L3 vehicle killed a woman

=> First fatal crash involving a pedestrian

Temple, Arizona, March 2018

- ✓ ***Despite the presence of multiple sensors (lidars, cameras …), the <u>perception system failed to detect the pedestrian & didn't disengaged</u>***
- ✓ ***The Safety Driver reacted too lately*** *(1s before the crash)*

AVs have to face two main challenges

Challenge 1: The need for **Robust**, **Self-diagnosing** & **Explainable** **Embedded Perception**

Video Scenario:

- *The Tesla perception system failed to detect the barriers blocking the left side route*
- *The driver has to take over and steer the vehicle away from the blocked route (for avoiding the collision)*

Video source: AutoPilot Review @ youtube.com

Challenge 2: The need for **Understandable Driving Decisions** *(share the road with human drivers)*

Human drivers actions are determined by a complex set of interdependent factors difficult to model *(e.g. intentions, perception, emotions …)*

⇒ ***Predicting human driver behaviors is inherently uncertain***

⇒ ***AV have to reason about uncertain intentions of the surrounding vehicles***

Video scenario:

*Scene observed by the dash cam of a **bus** moving behind the Waymo AV*

- ***Waymo AV** is blocked by an obstacle and it decides to execute a left lane change*
- *The **bus driver** misunderstood the Tesla's intention and didn't yield*
- *The two vehicles collided*

Video source: The Telegraph

Embedded Bayesian Perception & Decision-making

Main Challenges & Required Technological Breakthrough

=> Robustness, Efficiency, Dynamic Human Environments (Safety is still not guaranteed)

=> Real-time integration of Perception & Motion planning & Control

=> Integration into Embedded Hardware & Software (future products)

=> Validation & Certification

ADAS & Autonomous Driving

Perception & Decision-making requirements for AVs

Dynamic Scene Understanding & Navigation Decisions

Situation Awareness & Decision-making

⇒ *Sensing + Prior knowledge + Interpretation*
⇒ *Selecting appropriate Navigation strategy (planning & control)*

Embedded Perception & Decision-making for Safe Intentional Navigation

Dealing with unexpected events

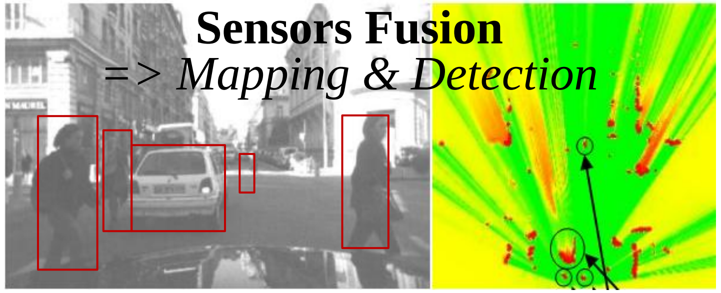
Anticipation & Risk Prediction technologies
for avoiding upcoming collisions with "something"
=> *High reactivity & reflexive actions*
=> *Focus of Attention & Sensing*
=> *Collision Risk estimation + Avoidance strategy*

Main features

- ✓ Dynamic & Open Environments => *Real-time processing & Reactivity (several reasoning levels are required)*
- ✓ Incompleteness & Uncertainty => *Appropriate Model & Algorithms (probabilistic approaches)*
- ✓ Sensors limitations (no sensor is perfect) => *Multi-Sensors Fusion*
- ✓ Hardware / Software integration => *Satisfying Embedded constraints*
- ✓ Human in the loop (mixed traffic) => ***Human Aware Decision-making process (AI based technologies)***
  Taking into account Interactions + Behaviors + Social rules (including traffic rules)

1st Paradigm : Embedded Bayesian Perception

Embedded Multi-Sensors Perception
⇒ ***Continuous monitoring of the dynamic environment***



❑ Main challenges

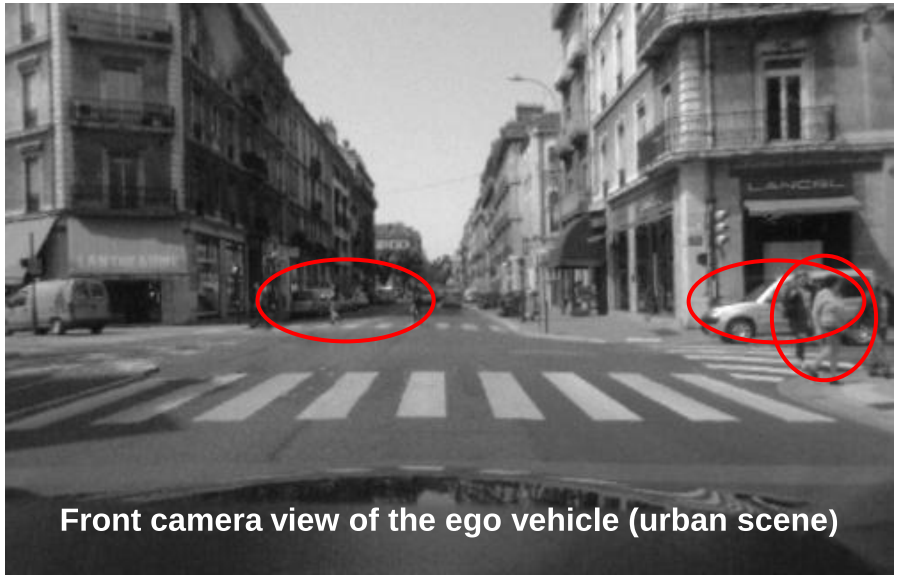
- ✓ *Noisy data, Incompleteness, Dynamicity, Discrete measurements*
- ✓ ***Strong Embedded & Real time constraints***

❑ Our Approach: Embedded Bayesian Perception

- ✓ *Reasoning about **Uncertainty** & **Time window** (Past & Future events)*
- ✓ ***Improving robustness** using **Bayesian Sensors Fusion***
- ✓ ***Interpreting the dynamic scene** using **Contextual & Semantic** information*
- ✓ ***Software & Hardware integration** using GPU, Multicore, Microcontrollers…*

Dynamic Probabilistic Grid & Bayesian Filtering – *Main Features*

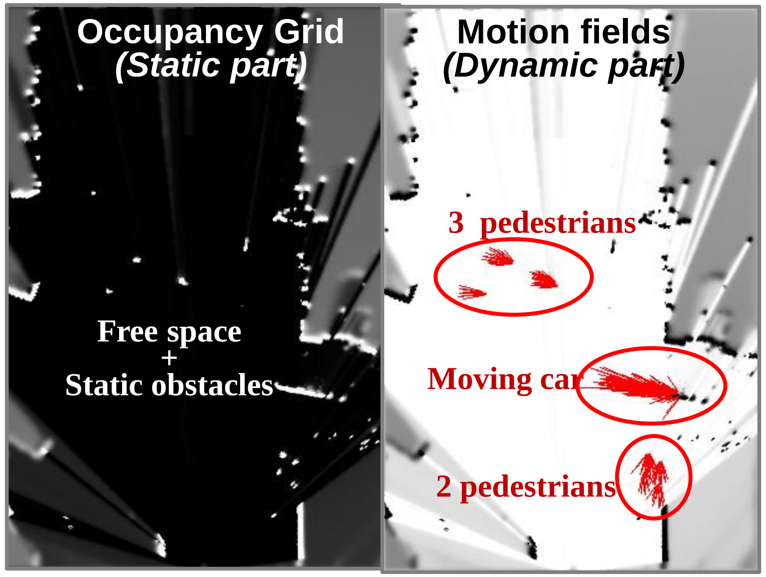
Exploiting the dynamic information for a better understanding of the scene



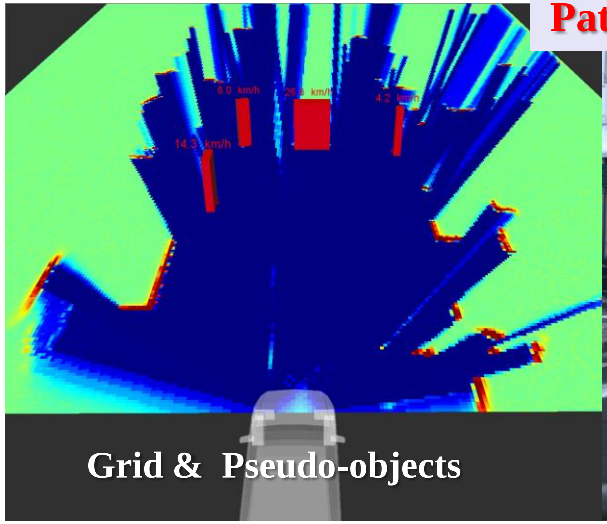
Front camera view of the ego vehicle (urban scene)

Sensors data fusion
+
Bayesian Filtering
+
Extracted Motion Fields

1st Embedded & Optimized version (HSBOF, patent 2014)

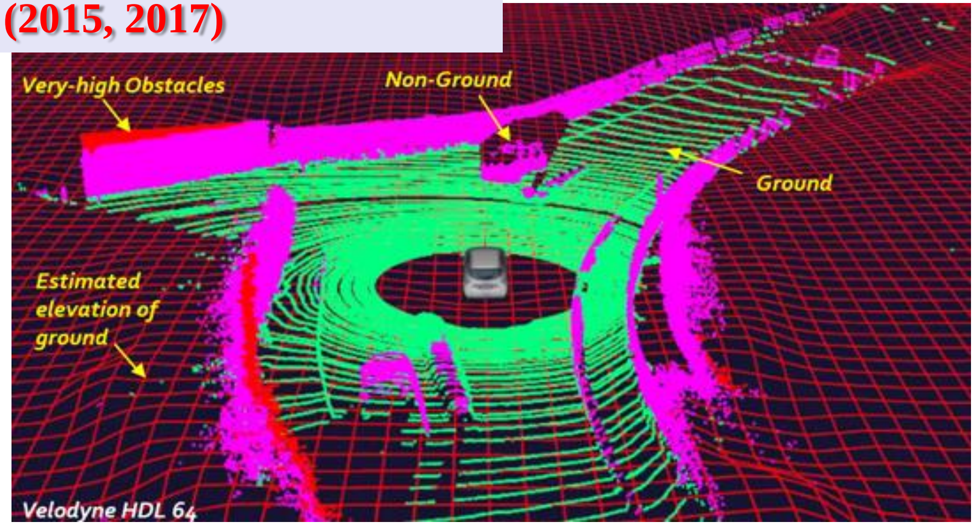


Patented Improvements & Implementations (2015, 2017)



Grid & Pseudo-objects

Classification *(using Deep Learning)*

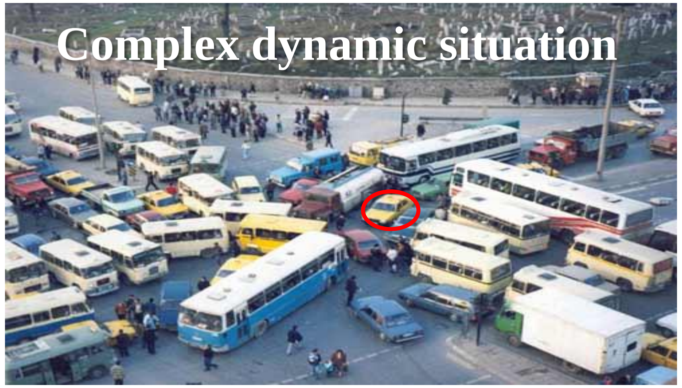


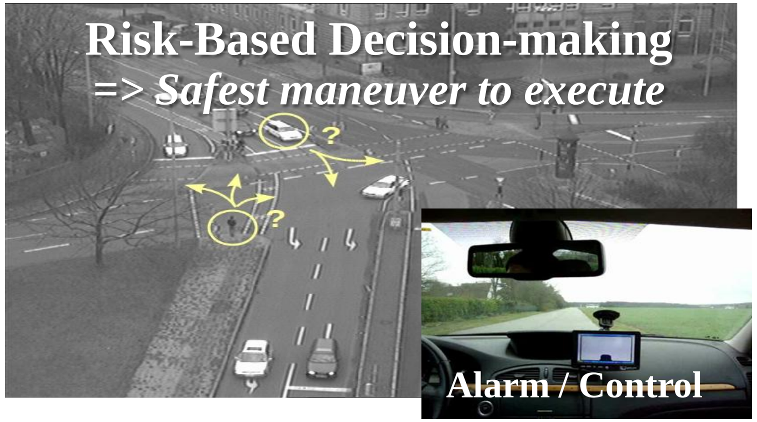
Detection & Tracking + Moving Objects Classification
=> CMCDOT 2015 (including a "Dense Occupancy Tracker")

Ground Estimation & Point Cloud Classification (patent 2017)

2nd Paradigm: Collision Risk Assessment & Decision-making

Decision-making for avoiding Pending & Future Collisions





- **Main challenges**

  Uncertainty, Partial Knowledge, World changes, Real time

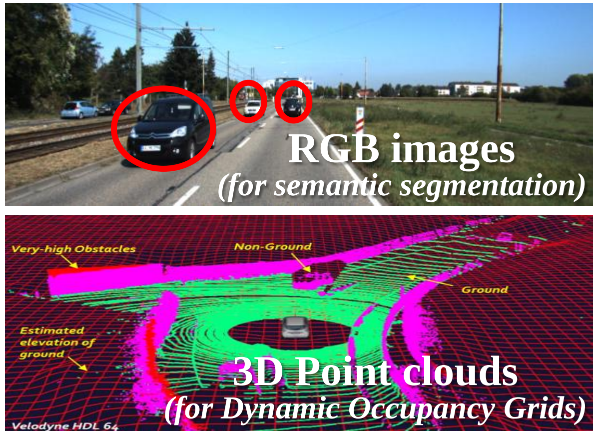
  Human in the loop + Unexpected events + Navigation Decision based on Perception & Prior Knowledge

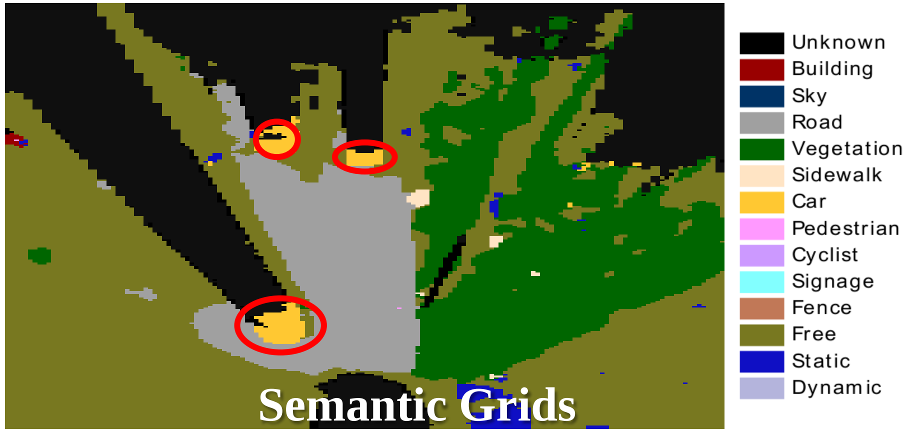
- **Approach: *Prediction + Risk Assessment + Bayesian Decision-making***
  - ✓ *Reason about **Uncertainty & Contextual Knowledge** (using **History** & **Prediction**)*
  - ✓ *Estimate **Probabilistic Collision Risk** at a given **time horizon t+δ** (δ = a few seconds)*
  - ✓ *Make **Driving Decisions** by taking into account the **Predicted behavior** of all the observed surrounding traffic participants (cars, cycles, pedestrians …) & **Social / Traffic rules***

- **Decision-making: *Two types of "collision risk" have to be considered***
  - ✓ ***Short-term collision risk** => Imminent collisions with "something" (unclassified), time horizon <3s, conservative hypotheses*
  - ✓ ***Long-term collision risk** => Future potential collisions, horizon >3s, Context + Semantics, Behavior models*

3rd *Paradigm:* Models improvements using Machine Learning

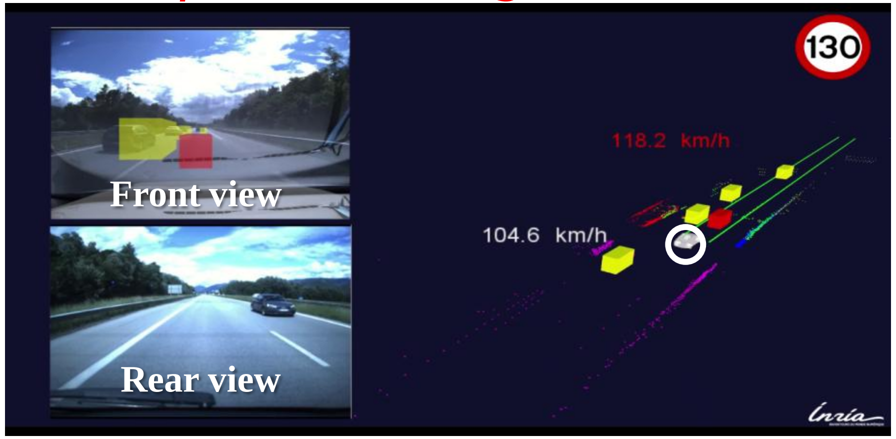
❑ Perception level: *Construct "Semantic Grids" using Bayesian Perception & DL*





❑ Decision-making level: *Learn driving skills for Autonomous Driving*

- ❖ *1st Step:* ***Modeling Driver Behavior*** *using Inverse Reinforcement Learning (IRL)*
- ❖ *2nd Step:* ***Predict motions*** *of surrounding vehicles &* ***Make Driving Decisions*** *for Ego Vehicle*



4th Paradigm: Combining Motion Planning & Safe navigation

Global planner – Hybrid-State E*

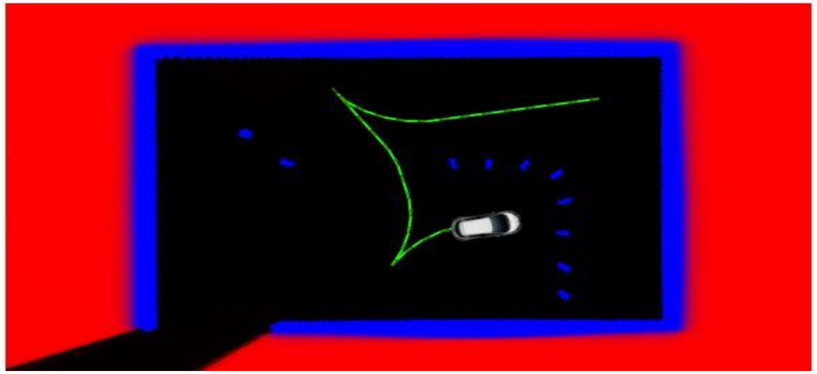
Pros & cons

+ Considers occupancy uncertainty
+ Continuous path even at low resolution
+ Allows complex maneuvers
+ Favors simple maneuvers
- Discrete space representation
- No obstacle motion

Future work

- Use exact vehicle shape
- Online replanning

Example of a computed path



Local planner – DWA

Accuracy

- Accurate trajectory prediction
- Accurate ego vehicle shape

Computing efficiency

- Massively parallel computations over ego vehicle positions and trajectories

Simplicity

- Only simple trajectories
- Short term prediction (5-10s)

Command sampling illustration

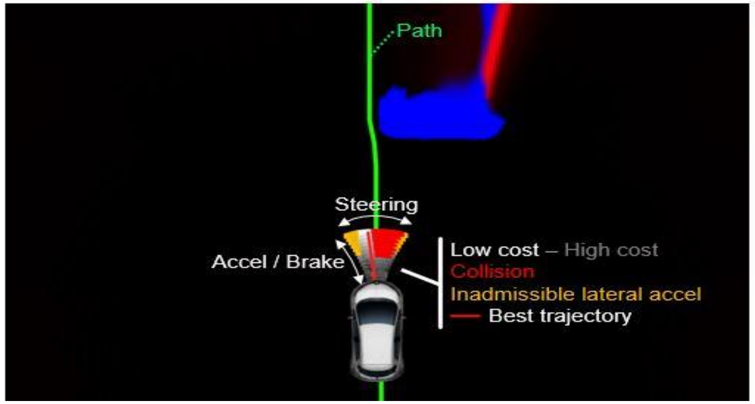


Illustration: Video demos IROS 2018 (Madrid)